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Optimization of Manufacturers Behaviour On the Basis of a Local Economic Agent-Based Model Implementation

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Abstract: In the era of globalization, local economic structures have not lost their significance and must be in the focus of a scientific research. Optimization problem solution could become a solid theoretical foundation for a local economic system effective functioning. To express an objective function in the analytical form in order to implement precise mathematical methods is impossible for a complex system, an economic system has proved to be such type system. Methods based on simulation are believed to be effective for finding solutions of a wide range of optimization problems. This paper details findings of the research aimed at solving optimization problem in terms of revealing optimal agent behavior in the course of exchanges in a local economic system on the basis of agent-based modeling usage.

Keywords: optimization, local economic system. strategy, agent-based model, simulation

1. INTRODUCTION

It becomes common knowledge that globalization processes have been intensifying while several last decades. As globalization one can understand “a process of interaction and integration among the people, companies, and governments of different nations, a process driven by international trade and investment and aided by information technology” (Globalization101). But, does it mean that local economic systems could not be in the focus of scientific research?

Michael Porter answered this question by developing Cluster theory, which stresses importance of a local economy which was named “a cluster” by the author. He determined a cluster as “a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities” (Porter Michael E., 2000).

The term “glocalization” also emphasize the role of a local economic system in the global economics. Being a portmanteau of globalization and localization (localism) terms (Johannisson B., 2009), glocalization concept tries to reconcile globalization and localization concept in a one, it advocates the idea that modern economic processes flow simultaneously into two opposite afore mentioned directions and postulates the fact that the global is not a one-dimensional space but a kind of trans-local reality.

Having justified local economic system significance for the today world, in this paper we try to develop possible optimization problem solution for the sake of a local economic system effective functioning.

The term “Optimization” is referred to a procedure or procedures employed to create a system, algorithm, decision or design as effective or functional as possible. In the mathematical theory “optimization” is understood as the process of finding the best solution of a problem from a set of available alternatives (Vasyliev F.P., 2011). The general expression of optimization problem is to find such values of controllable parameters that would yield an extreme value of the objective function:

$$extremum_{\vec{\theta}\in\Theta} J(\vec{\theta}) \qquad (1)$$

where $\vec{\theta}$ represents the input variables vector, $J(\vec{\theta})$ is the objective function and Θ is a set of constraints that may be either explicitly given or implicitly defined (Fu M.C., et.al., 2005).

As a rule of thumb, the analytic form can be obtained only for the objective function of the system consisting of a small number of elements and having a small set of controllable parameters. Social and economic systems may be understood as complex systems (Arthur W.B. ,2013) consisted of active, behaving in various ways, and passive elements. The system size (element number) can be enormous, characteristics can be very individual, and all this removes the possibility to analytically express the objective function.

Methods based on simulation are believed to be effective for finding solution for a wide range of optimization problems. This technology is known as a simulation-based optimization, or simulation optimization. These methods are used to solve problems where $J(\vec{\theta})$ function cannot be represented in a mathematical form. Objective function values obtained in experiments based on a software model and these values are often computed approximately.

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The most general form of the objective function expression for cases being discussed employs the mathematical expectation (E):

$$J(\theta) = E[L(\vec{\theta}), \omega)], \quad (2)$$

where ω is an experiment with the model (simulation replication), and L is the sample performance measure (Fu M.C., et.al., 2005).

One can find detailed description of simulation optimization methods in several papers (Carson Y. et. al, 1997; Fu M. C. et.al, 2000, 2005; Hong L. J., 2009; Pasupathy R. et.al. 2013; Amaran S. et.al, 2016), and books (Spall J. C., 2003; Kleijnen J. P. C., 2008; Chen C. H. and Lee L. H., 2010).

Agent-based technology is proved to be the most oriented towards social and economic systems (Borrill, P.L. and Tesfatsion, L., 2010). With the help of developed agent models one can receive a set of values of the objective function and then use the ranking and selection methodology (Fu M.C., 2005) in order to find the optimal value.

Agent-based model is a dynamic system with autonomous active entities (agents) which communicate with each other in a certain environment (Macal C.M. and North M.J., 2010). Having determined the agent behaviour and having run the model, one gains the opportunity to examine the system as a whole, i.e. to receive system macro parameters (Chen, S.H. 2011). In (Duffy, J., and Unver, M. Utku, 2008; Harras G., Sornette D., 2011) one can find interesting examples of agent-based simulation usage in the economic domain.

Agents can greatly differ from each other and their behaviour can be different as well. They can behave in a random way (Zero Intelligence Agents) or they can gain and store their knowledge. Nevertheless, even when the agents are simple, one can receive valuable results from simulation.

This paper details results of the research aimed at solving the problem of finding optimal agent behaviour in the course of exchanges in a local economic system on the basis of agent-based simulation.

2. STRATEGY MODEL AS A COMPONENT OF THE MODEL SET

The main process running in every socio-economic system is a communication process: active entities of the system exchange something in a material or non-material form that has value (Luhmann N., 2007). In a social system knowledge is the value subject for exchange, in an economic system money and products exchanges can be observed.

A set of agent-based program models was developed in Netlogo modelling framework (Wilenky U., 1990) to simulate communication process in a local economic system as a series of exchanges, and this set is thoroughly discussed in (Zvereva O.M., 2017). Different models were aimed at solving different problems of a local economic system. Main information about this set is collected in Table 1. One of these models, which is called the Strategy Model, is oriented towards optimization problem solution: it helps to detect the agent behaviour which may be considered as an optimal one. Main window screenshot of this model is shown in Fig. 1.

The Basic Model has become a basis for all other models in the set as it realizes the basic algorithm of economic agent exchanges, which form the whole process that was interpreted as a communication process.

To understand the Strategy Model algorithm of functioning, it is reasonable to describe the basic algorithm and then discuss specific features of the Strategic Model algorithm.

Table1. Model set description

Model Name	Description (specific features)	Model Goal
Basic Model	Basic model algorithm is realized, all other models were built on this basis.	Model communication process as a sequence of exchanges between agents
Strategy Model	Economic agents acting in the model may have different types of behaviour (strategies).	To determine the optimal strategy (optimization problem solution)
Municipality Model	This model is based on the real statistical data	To verify theoretical resuts on the real data base
Open System Model	Environmental agents are introduced to model interrelations with environment	To determine whether virtual money introduction can improve a communication process
Manufacturing Model	Manufacturing stage is coded, after it, product volumes can be corrected to provide system sustainability	To determine whether a system can go back into the sustainable state after equilibrium violation

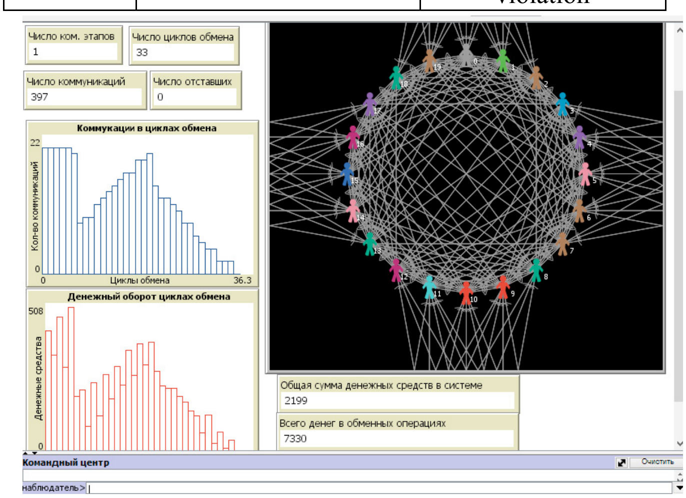

Fig. 1. Strategy model screenshot

The basic algorithm (Basic Modelfunctioning) is based on the Leontief's static equilibrium (Leontief V.V., 1990). N agents act, and every agent produces a unique product. The *i-th* agent product volume is denoted as x_i. The ordered sequence of all agent product volumes forms $\vec{X} = [x_1, x_2, \dots, x_N]$, which is the production vector of the economic system under study.

The *i-th* agent should consume the other agent's products in order to manufacture its own product of value x_i. These consumption volumes are denoted as w_{ki}, where w_{ki} indicates the *i-th* agent consumption of the *k-th* agent's product. Then $\vec{W_i}$ is the i-th agent consumption vector $\vec{W_i} = [w_{1i}, w_{2i}, \dots, w_{iN}]$.

Every consumption volume (w_{ki}) is in direct proportion to x_i and is determined by the *i-th* agent productive technology. Technical (input) coefficients estimated as $a_{ki} = \frac{w_{ki}}{x_i}$ are dimensionless. These coefficients a_{ki} ($k=1..N$, $i=1..N$) comprise structural matrix, or table (A). Matrix element a_{ki} determines the *k-th* agent's product volume which is consumed by the *i-th* agent for its single product unit manufacturing.

Then the *i-th* agent consumption vector can be expressed as $\vec{W_i} = [a_{1i} \cdot x_i, a_{2i} \cdot x_i, \dots, a_{ni} \cdot x_i]$.

After product exchanges every agent has a remaining volume of its own product. Partly it can be used in its manufacturing process (this is reflected in $\vec{W_i}$ and the structural matrix) and the last part denoted as y_i can be spent to meet the internal non-productive needs. Vector $\vec{Y}$ is known as a vector of final demands ($\vec{Y} = [y_1, y_2, \dots, y_N]$

For every (*i-th*) agent it is true that:

$$x_i = a_{1i} \cdot x_1 + a_{2i} \cdot x_2 + \dots + a_{Ni} \cdot x_N + y_i \tag{3}$$

Static form of Leontief's Equilibrium (SLE) is settled by the following vector equation:

$$\vec{X} - A\vec{X} = \vec{Y} \tag{4}$$

where $\vec{X}$ and $\vec{Y}$ are calculated in money value.

To provide exchanges the *i-th* agent uses money (m_i) it has on its account. Initial value of the agent's money (m_i) is estimated in direct proportion to its product volume ($m_i = K \cdot x_i$), where K is the Money supplement coefficient, this coefficient is the same for every agent in the system.

Communication process is divided into exchange cycles. During an exchange cycle every randomly chosen agent receives a chance to communicate with the other agents in order to buy necessary products (exchange money for products).

Agents can behave in different ways. These different kinds of agent behavior were named "strategies". Strategies dictate the volume of exchange and the rule of partner choice. Table 2 describes strategies under review.

The First strategy one can recognize as a "list strategy". Agent chooses a partner for exchange in the order of its consumption vector: every agent observes its consumption vector successively from the beginning to the end and looks for the first non-zero element in it. If it finds such a value, its position in the list denotes the number of the agent which is going to become a partner (a salesman of the product for consumption). The exchange volume is set to the maximum possible level estimated as minimum of three values: the agent chosen consumption demand, current money balance on its account, and the current product volume of the partner agent.

The Second strategy was named the "Maximum strategy". An agent chooses the partner for communication in accordance with its maximum consumption demand. It observes its current consumption vector successively from the beginning to the end and looks for the maximum value in it. When it finds this value, its vector position denotes the partner agent number. The exchange value is estimated in the same way as in the First strategy.

The Third strategy can be characterized as a "uniform" one. It differs greatly from the two strategies described above. Every agent in the exchange cycle tries to communicate with all system agents whose products are in demand. The agent tries to buy their products in equal volumes. Exchange volume is estimated as the quotient of the agent's money balance and the number of non-zero elements in its current consumption vector

Table 2. Description of strategies

Strategy	Partner (j-th agent) characteristics	Exchange volume
First (List) Strategy	$\exists j: w_{ji} = 0, \forall k \in [1..j]: w_{ki} = 0,$ $w_{ji} \in \vec{W_i}, w_{ki} \in \vec{W_i}$	$min(w_{ji}, x_j, m_i)$
Second (Maximum) Strategy	$\exists j: w_{ji} \neq 0, w_{ji} = \max_{1 \le k \le N}(w_{ki}),$ $w_{ji} \in \vec{W_i}, w_{ki} \in \vec{W_i}$	$min(w_{ji}, x_j, m_i)$
Third (Uniform) Strategy	$: w_{ji} \neq 0, w_{ji} = \max_{1 \le k \le N}(w_{ki}),$ $w_{ji}(t) \in \vec{W_i}, w_{ki} \in \vec{W_i}$	$\frac{m_i}{L}$, L is the number of non-zero elements
Fourth (Consequent) Strategy	$\exists j: w_{ji} \neq 0, (\forall k \in [i+1 \dots j]: w_{ki} = 0)$ or $(\forall k \in [1..j-1]: w_{ki} = 0),$ $w_{ji} \in \vec{W_i}, w_{ki} \in \vec{W_i}$	$min(w_{ji}, x_j, m_i)$
Fifth (Neighbourhood) Strategy	$\exists j: w_{ji} \neq 0: (\forall k \in [i+1 \dots j-1]; w_{ki} = 0) or (\forall k \in [j-1..1]: w_{ki} = 0),$ $w_{ji} \in \vec{W_i}, w_{ki} \in \vec{W_i}$	$min(w_{ji}, x_j, m_i)$

The Fourth strategy considered as the "Consequent" strategy works as follows. Every agent begins to find a partner according to its consumption vector but in the positions which are subsequent to its own position. If all of these succeeding demands are met, then the agent starts from the beginning of its consumption vector and tries to find a non-zero element in the positions preceding to its own. The exchange volume is estimated in the same way as in the First and Second strategies.

If to discuss the "Neighbourhood strategy", every agent begins to find a partner according to its consumption vector but in its neighborhood. If we discuss the i-th agent, it begins to consider the $(i+1)$-th agent, and if the exchange is impossible, then the $(i-1)$-th agent is to be its partner. If both mentioned exchanges are impossible, the agent-initiator widens its neighborhood and tries to communicate with the $(i+2)$-th and $(i-2)$-th agents. If these attempts fail, then the $(i+3)$-th and $(i-3)$-th agents are under consideration, and etc. The exchange volume is estimated in the same way as in the First, Second and Fourth strategies. The ordered sequence of all agent strategies forms $\overrightarrow{STR}$. As the result, the initial conditions of the model are as follows:

- N agents are created;
- $\vec{X}, \vec{Y}, A, \overrightarrow{M}, \overrightarrow{STR}$ are determined;
- The rule for exchange performing can be expressed as:

$$IF\ (\exists \mathrm{i}, \mathrm{j}: (\mathrm{Ag_i} \rightarrow \text{"ready to buy"})\&(\mathrm{Ag_j(t)} \rightarrow \text{"ready to sell"})) \mathrm{THEN}\ (\mathrm{EXCHANGE()})),$$

$$Ag_i \rightarrow \begin{cases} \text{"ready to buy"}, & \text{если } ((x_{\mathrm{j}} > 0)\&(w_{ji} > 0)) \\ \text{"not ready to buy"}, & \text{otherwise} \end{cases}$$

$$Ag_j \rightarrow \begin{cases} \text{"ready to sell"}, & \text{если } ((x_{\mathrm{j}} > 0)\&(w_{ji} > 0)) \\ \text{"not ready to sell"}, & \text{otherwise} \end{cases}$$

3. OPTIMIZATION PROBLEM STATEMENT

As an objective value we can take the time required to complete all exchanges (all agents have received the necessary resources through exchanges) or exchanges of a single agent. Model time can be measured in exchange cycles and in exchange operations. As an objective value we also can take the time necessary to commence agents' production (when all agents receive enough resources to start their manufacturing activity). The controllable parameter is the agent strategy; the Money supplement coefficient (K) is assumed to be an explicit constraint. The primary goal is to find the minimum objective value.

4. DATASETS FOR EXPERIMENTS

Experiments were based on three datasets. To make the results comparable all these datasets were calculated for 20 agents. Agents, engineered on the basis of these datasets, are equal in terms of their technical characteristics. It means that they have equal output volumes (x_i=500), they sale equal volumes of their products, and they have equal volumes of final demands (y_i=115). Other dataset characteristics are given in Table 3.

Table 3. Datasets used in experiments

Data Set	Structural Matrix (A)
1	$\forall i \in [1..20], \forall j \in [1..20],\ \ a_{ij} = 0{,}0385$
2	$\forall i = \in [1..20], \forall k \in [1..20], \sum_{i=1}^{20} a_{ki} = \sum_{i=1}^{20} a_{ik} = 0{,}77$
3	$\begin{cases} \forall k \in [1..20], \sum_{i=1}^{20} a_{ki} = \sum_{i=1}^{20} a_{ik} = 0{,}77 \\ \forall m \in [1..20], \forall n \in [1..20], \quad a_{mn} = a_{nm} \end{cases}$

In the first dataset all agents have equal consumption demands for products of the other agents, every structural matrix (A) element is equal to 0,385. The second dataset is made for agents that have equal total demands for the other agents' products. In the third dataset, besides equal total agents' demands, the condition of mutual demand equality is true (i.e. every *i-th* agent tries to consume the *k-th* agent product in the same volume as the *k-th* agent tries to consume the *i-th* agent product).

5. EXPERIMENTAL RESULTS

In the course of the experiments the agent strategies were investigated implementing the Strategy model and taking the aforementioned datasets (Table 3) as input data for the model. A special attention was paid to strategy choice impact to the time characteristics such as:

1. time interval required for completion of all exchanges (communication process time);
2. time interval required for commencement of the manufacturing process (all agents have become capable of starting their production);
3. time interval necessary for a single agent to complete its exchange operations.

In the experiments different cases were observed: when all agents have the same strategy for their behaviour and when some agents have one kind of strategy while others try to act differently (strategy mixture). In this paper, the case of same strategies usage is in the focus of discussion. As a result, the optimal strategy could be determined.

First, optimization problem was stated in the following way: to find a strategy that provides the minimal time interval (measured in exchange cycles) for completion of exchanges at a predetermined value of the coefficient K. The received results are reflected by Fig. 2, as input dataset the second dataset (Table 3) was used.

From Fig. 2 it becomes evident that the optimal strategy for the overall system is the Fourth (Consequent) one. The time interval necessary to complete all exchanges is the smallest when all agents behave in accordance with the Fourth strategy. The worst case for the system almost for all money supplement coefficient values (K) is the situation when the agents used the First strategy, while the Second and the Fifth strategies are the intermediate ones. If we try to sort strategies according to their optimality in the view of communication process time (the more optimal – the first), we will receive the following list: The Fourth (Consequent), the Fifth (Neighbourhood), the Second (Maximum), the First (List).

The Third (Uniform) strategy was excluded from consideration and comparison in this case, because it has different internal rules of exchanges. We won't have valid comparison with the others under these criteria, as it assumes several exchanges of one agent as initiator in one exchange cycle.

As we mentioned above, optimization problem can be stated in another way: to find the strategy that will provide the minimal time necessary to start manufacturing by all agents in the system. Manufacture run by agents is the main goal of every productive system, all exchanges in the system are made to achieve this goal. An agent has a chance to start manufacturing if it has some volume of every necessary product (every consumption demand of it has been met, at least in a minimal volume). Namely the Third strategy, as compared with the others, yields an increased number of operations, but it appears to be the optimal one in terms of early commencement of manufacturing.

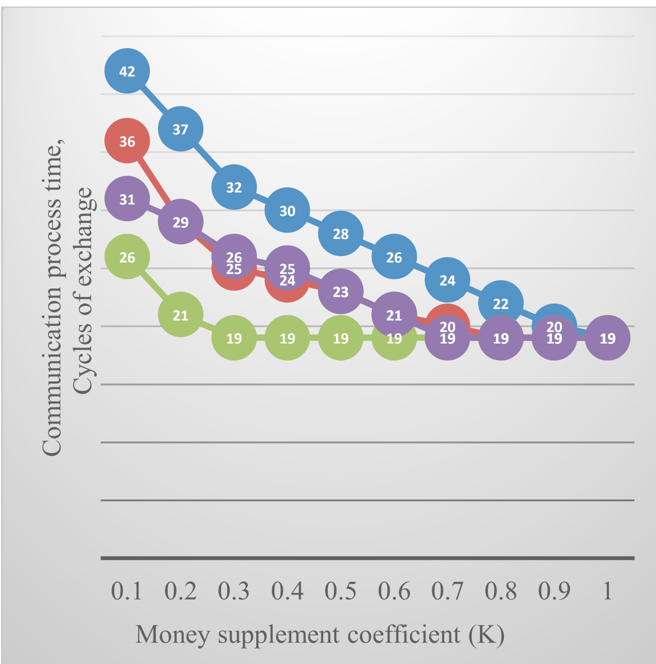

Fig. 2. Comparison of strategies in terms of communication process time (1 Strategy – in blue; 2 Strategy –in red; 4 Strategy – in green; 5 Strategy – in violet)

As to discuss time interval necessary for a single agent to complete its exchange operations, an interesting phenomenon was revealed. This effect is related to a single agent strategy change in the system with a mixture of strategies. Possibility of a phenomenon revealing due to agent-based modelling was predicted by E. Bonabeau and described in (Bonabeau, 2002).

The aforementioned phenomenon might be understood as a "selfishness" (egoistic) phenomenon. This effect is developed when one agent changes its strategy to the less optimal in the system where at least a half of agents (or more) exercise the more optimal strategy. This act makes the whole system situation worse (it takes longer to complete exchanges) and the neighbours of this agent suffer as well. But the agent itself gains serious advantages: in comparison to previous cases (with its old strategy), it meets its demands faster.

For example, there was a series of experiments, where a half of the agents performed the First strategy (the least optimal), and a half – the Second one (more optimal, see Fig. 2). If one of the second half agents implemented the First strategy, i.e. used the First strategy instead of the Second, it finished its exchanges in one or two exchange cycles earlier than in previous experiments. Thus, one can make a conclusion that the less optimal strategy delivers an advantage to its implementer and spoilы the whole situation in the system.

6. CONCLUSIONS

In this paper we have introduced the example of optimization problem solution by means of agent-based simulation. Optimization problem was formulated in following ways:

- to find a strategy resulting in the minimal time of communicating process for the determined money supplement coefficient;
- to find a strategy resulting in early commencement of manufacturing in the agent system;
- to find a strategy that appears to be optimal for a single agent.

This research produced the following outcome:

- In terms of the minimum time for successful completion of exchanges in the system, the Fourth strategy proved to become optimal (all agents have to behave in accordance with the Fourth strategy rules);
- In terms of the minimum time necessary for a single agent to complete its exchange operations in order to meet its demands, also the Fourth strategy may be understood as an optimal one (it means that all agents use the same strategy, in the case when there is a mixture of strategies "selfish" phenomenon was revealed);
- To minimize the time for commencement of manufacturing in the system all agents have to be in favour of the Third strategy;
- The most "selfish" strategy is the First strategy as it helps to minimize the exchange time of a single agent, at the same time this strategy is the least optimal in the view of the whole system communication process;
- The experiments prove that the exchange time is minimal for the agents on the top of the list.

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